

Rewritable optical data storage medium and use of such a medium

The invention relates to a rewritable optical data storage medium for high-speed recording by means of a focused radiation beam, said medium comprising a substrate carrying a stack of layers, which stack comprises, a substantially transparent first auxiliary layer I1, a substantially transparent second auxiliary layer I2 having a thickness d_2 , and a recording layer of a phase-change material having a thickness d_p and comprising at least a composition $\text{Ge}_x\text{Sn}_y\text{Sb}_{1-x-y}$, where $0.05 < x < 0.30$ and $0.15 < y < 0.30$, which recording layer is interposed between I1 and I2, and a third auxiliary layer I3 with a thickness d_3 acting as a heat sink and being present at a side of I2 opposite to the side of the recording layer.

The invention also relates to the use of such an optical data storage medium.

An embodiment of an optical data storage medium of the type mentioned in the opening paragraph is known from European patent application EP 1343154 A2.

In this document $\text{Ge}_x\text{Sn}_y\text{Sb}_{1-x-y}$ compositions have been proposed as a phase-change material for high-speed rewritable recording. The crystallization speed of the phase-change material depends on the phase-change composition. By varying the Ge-content in the range 5-30 atomic percent, discs can be designed suitable for recording at 2-16x DVD+RW.

An optical data storage medium based on the phase change principle is attractive, because it combines the possibilities of direct overwrite (DOW) and high storage density with easy compatibility with read-only optical data storage systems. Phase-change optical recording involves the formation of submicrometer-sized amorphous recording marks in a crystalline recording layer using a focused relatively high power radiation beam, e.g. a laser-light beam. During recording of information, the medium is moved with respect to the focused laser-light beam that is modulated in accordance with the information to be recorded. Marks are formed when the high power laser-light beam melts the crystalline recording layer. When the laser-light beam is switched off and/or subsequently moved relatively to the recording layer, quenching of the molten marks takes place in the recording layer, leaving an amorphous information mark in the exposed areas of the recording layer that remains crystalline in the unexposed areas. Erasure of written amorphous marks is realized by

recrystallization through heating with the same laser at a lower power level, without melting the recording layer. The amorphous marks represent the data bits, which can be read, e.g. via the substrate or a cover layer, by a relatively low-power focused laser-light beam. Reflection differences of the amorphous marks with respect to the crystalline recording layer bring about a modulated laser-light beam which is subsequently converted by a detector into a modulated photocurrent in accordance with the recorded information.

One of the most important demands in phase-change optical recording is a high recording speed or data rate, which means that data can be written and rewritten in the medium with a relatively high linear recording speed of e.g. at least 35 m/s. Such a high data rate requires the recording layer to have a high crystallization speed, i.e. a short crystallization time, during DOW. To ensure that previously recorded amorphous marks can be recrystallized during DOW, the recording layer must have a proper crystallization speed to match the velocity of the medium relative to the laser-light beam. If the crystallization speed is not high enough the amorphous marks from the previous recording, representing old data, cannot be completely erased, meaning recrystallized, during DOW. This causes a high noise level. A high crystallization speed is particularly required in high-density recording and high data rate optical recording media, such as in disk-shaped CD-RW high speed, DVD-RW, DVD+RW, DVD-RAM, BD which are abbreviations of a new generation high density Digital Versatile Disk+RW, where RW refers to the rewritability of such disks, and Blu-ray Disc (BD), where blu refers to the used laser wavelength, i.e. blue. For these disks the complete erasure time (CET) has to be relatively low. CET is defined as the minimum duration of an erasing pulse for complete crystallization of a written amorphous mark in a crystalline environment. The CET is directly related to the maximum DC-erase velocity V_{emax} . This V_{emax} , inter alia, determines the maximum recording speed. For DVD+RW, which has a 4.7 GB recording density per 120 mm disk, a recording speed of 35 m/s corresponds to a recording velocity of 10 times (10X) the normal velocity. For the other formats this number may vary. For high speed versions of DVD+RW and BD data rates of 50 Mbits/s, corresponding to about 4x DVD and 1x Blu-ray) and higher (10x DVD ~110 Mbit/s, are required. For complete erasure of an amorphous mark, two processes are known, i.e. crystallization by nucleation and crystallization by grain crystallite growth. Nucleation of crystallites is a process where nuclei of crystallites are randomly formed in the amorphous material. Therefore the probability of nucleation depends on the volume, e.g. thickness, of the recording material layer. Grain growth crystallization may occur when crystallites are already present, e.g. the crystalline surroundings of an amorphous mark or crystallites which have

been formed by nucleation. Grain growth involves the growth of those crystallites by crystallization of amorphous material adjacent the already present crystallites. In practice both mechanisms may occur in parallel but generally one mechanism dominates over the other in terms of efficiency or speed.

5 Another important demand in phase-change optical recording is a high data stability, which means that recorded data, usually in the form of amorphous marks, remain intact for a long period of time. A high data stability requires the recording layer to have a low crystallization rate, i.e. a long crystallization time, at temperatures below 100°C. During archival storage of the optical data storage medium, written amorphous marks recrystallize at a certain
10 rate, which is determined by the properties of the recording layer. When marks are recrystallized they cannot be distinguished anymore from the crystalline surrounding, in other words: the mark is erased. For practical purposes a recrystallization time of at least 100 years at room temperature, i.e. 30°C, is needed.

 In EP 1343154 A2 the medium of the phase-change type e.g. comprises a disc-
15 shaped substrate of a resin having thereon a 10-100 nm thick first protective layer of a dielectric material, a 10-20 nm-thick recording material layer of a phase-change alloy, a second protective layer of a dielectric material, and a 10-500 nm thick reflective layer of mainly Ag. Such a stack of layers can be referred to as an IPIM-structure, wherein I represents a dielectric layer and P represents a phase-change recording layer and M a metal
20 layer. In said document the second protective layer preferably is at least 10 nm thick in order to suppress deformation of the recording layer. The thickness of each of the recording layer and the protective layer is selected so as to provide good laser light absorbing efficiency and to increase the amplitude of the recording signals, i.e. to increase the contrast between a recorded state and a non-recorded state in consideration of an interfering effect caused by a
25 multilayer structure, in addition to restrictions from mechanical strength and reliability. In writing amorphous marks, the mark length is ideally formed to a length nT , in which formula T is a reference clock period, n is a desired mark length which the mark may have by mark length modulation recording and is an integer. At high linear recording speeds recrystallization of the amorphous marks during recording, i.e. back growth of the interface
30 between amorphous mark and crystalline surrounding, or other distortion of the amorphous mark is likely to occur. In order to prevent this distortion a so-called write strategy is used whereby the marks are written employing a number of short recording pulses according to a predetermined scheme. At higher recording speeds this scheme becomes more complex and

more difficult to implement. Furthermore very short recording pulses are required for these complex schemes which are difficult to achieve.

5 It is an object of the invention to provide an optical data storage medium of the kind described in the opening paragraph, capable of being recorded at a relatively high linear recording speed.

 By relatively high linear recording speed a linear speed of about 35 m/s of the optical data storage medium relatively to the focused radiation recording beam is meant,
10 which e.g. corresponds to a speed of 10 times the normal DVD+RW recording speed, i.e. 10X.

 This object is achieved in accordance with the invention by an optical data storage medium of the kind described in the opening paragraph, which is characterized in that $\lambda_{12}/d_{12} > 5 \cdot 10^8 \text{ W m}^{-2} \text{ K}^{-1}$, in which formula λ_{12} is the heat conduction coefficient of the
15 material of the I2 layer. This coefficient is measured at room temperature using bulk material, e.g. target material in a sputtering deposition apparatus.

 A well-designed optical stack is important to diminish recrystallization within the write pulse, i.e. backgrowth. Applicants have had the insight that the amount of recrystallization depends on the crystallization speed of the phase-change material and the
20 heat transport in the stack. Especially for fast-crystallizing materials good heat transport is efficient to prevent recrystallization during writing. It is found by applicant that at recording speeds over 35 m/s (10x DVD+RW) and when the cooling of the recording layer P is relatively low, i.e. $\lambda_{12}/d_{12} < 5 \cdot 10^8 \text{ W m}^{-2} \text{ K}^{-1}$, proper recording is only achieved with a complicated 3T or 4T write strategy (WS), or with a 2T WS with extremely short pulses of
25 e.g. 2 ns or shorter. 2T, 3T or 4T refers to a WS where the number of pulses for recording a mark is reduced by approximately respectively a factor of 2, 3 or 4 compared to T. Writing an nT mark with T WS requires n pulses. By reduction of the number of pulses less backgrowth is achieved. However 3T and 4T write strategies require complicated schemes in order to compensate for the fact that when e.g. an nT mark has to be written n is mostly not
30 dividable by 3 or 4. A 2T write strategy is only usable when very short pulses are used which poses a practical problem on the recording laser and its driver. By applying proper cooling of the recording layer according to formula of claim 1 back growth of marks during writing is counteracted and a 2T WS with more realistic pulse lengths of e.g. 3 ns or 4 ns may be used successfully up to higher speeds.

In an embodiment the second auxiliary layer I2 mainly comprises $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and $d_{I2} < 10$ nm. This material is widely used in view of a high layer formation speed, small layer stress, a small volume change due to the change in temperature and an excellent durability against e.g. moisture. Contrary to what is known from prior art a relatively small thickness d_{I2} is advantageous for achieving high recording speeds. However a too small thickness d_{I2} will require too much write power (see Fig. 5A).

In another embodiment the second auxiliary layer I2 comprises at least one selected from the group of Ge_3N_4 , Si_3N_4 , Al_2O_3 , Hf_xN_y , ITO ($\text{In}_2\text{O}_3:\text{Sn}$) and Ta_2O_5 . These materials have a higher coefficient of thermal conductivity than $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and therefore thicker layers maybe used for achieving the same thermal conduction between the recording layer and the third auxiliary layer I3.

It is advantageous when the thickness d_p of the recording layer is smaller than 15 nm. This has the advantage that the recording layer may have a relatively high optical transmission, which is required in case of multi-stack optical media. In a multi-stack optical medium several recording layers are present. The recording/reading laser beam usually is directed through a "higher level" recording layer in order to record/read into/from a "lower level" recording layer in which case the higher level recording layer must be at least partially transparent for the laser beam in order to pass to the "lower level" recording layer. Applicants have found that the backgrowth of marks is also diminished by reducing the recording layer thickness. The value of d_p should not become too small because of other requirements, e.g. optical contrast and reflection. A minimum thickness would therefore be approximately 8 nm (see Fig. 6).

It is advantageous when the recording layer additionally comprises at least one selected from In, Ag or Cu. When these materials are present e.g. in a concentration up to 10 at.% it is possible to tune the crystallization speed of the phase-change material. The most important way to tune the crystallization speed of GeSnSb-based compositions is by varying the Ge-concentration. It is observed that between 10 and 15 at. % Ge, the crystallization speed increases dramatically. For this reason, it may be helpful to set the crystallization speed by addition of other elements. This is favorable in manufacture where always slight variations in concentrations during deposition will occur.

In an embodiment the third auxiliary layer I3 mainly comprises Ag. Ag is a material with a high coefficient of thermal conductivity. It is therefore suitable as a heat sink with a high heat dissipation capacity. The third auxiliary or reflective layer may additionally e.g. comprise at least one of the metals selected from a group consisting of Al, Ti, Au, Ag,

Cu, Pt, Pd, Ni, Cr, Mo, W and Ta or the like, including alloys of these metals in order to control the thermal conductivity of the reflective layer itself or to improve corrosion resistance. The addition amount is usually at least 0.01 at.% and at most 20 at.%.
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It is preferred that the thickness d_{13} of the third auxiliary layer I3 is at least 150 nm. A better heat dissipation is achieved which diminishes mark backgrowth even more.

It is advantageous that a substantially transparent fourth auxiliary layer I4 is present sandwiched between the third auxiliary layer I3 and the second auxiliary layer I2 screening the third auxiliary layer I3 from a chemical influence of the second auxiliary layer I2. Especially when Ag is used in the third auxiliary or reflective layer I3 the possibility of
10 e.g. S atoms of an auxiliary layer of $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ reacting with the Ag should be prevented. A suitable fourth auxiliary layer I4 comprises at least one of Si_3N_4 or Ge_3N_4 . Preferably the fourth auxiliary layer I4 has a thickness d_{14} equal or smaller than 3 nm. This small thickness will cause minimal interference with the thermal and optical properties of the stack.

15 An optimum thickness range for the first auxiliary layer, i.e. the layer through which the radiation beam, e.g. laser-light beam, enters first, is determined by a.o. the laser-light beam wavelength λ . When $\lambda=655$ nm an optimum is found around 60 nm.

The first auxiliary layer I1 may be made of a mixture of ZnS and SiO_2 , e.g. $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$. Alternatives are, e.g. SiO_2 , TiO_2 , ZnS, AlN, Si_3N_4 and Ta_2O_5 . A carbide may
20 be used, like SiC, WC, TaC, ZrC or TiC. These carbides give a higher crystallization speed and better cyclability than a ZnS- SiO_2 mixture.

The auxiliary layers may be provided by vapor deposition or sputtering.

The substrate of the optical data storage medium consists, for example, of polycarbonate (PC), polymethyl methacrylate (PMMA), amorphous polyolefin or glass. In a
25 typical example, the substrate is disk-shaped and has a diameter of 120 mm and a thickness of e.g. 0.6 or 1.2 mm. When a substrate of 0.6 or 1.2 mm is used, the layers can be applied on this substrate starting with the first auxiliary layer. If the radiation beam enters the stack via the substrate, said substrate must be at least transparent to the radiation beam wavelength. The layers of the stack on the substrate may also be applied in the reversed order, i.e. starting
30 with the third auxiliary layer, in which case the radiation beam will not enter the stack through the substrate. Optionally an outermost transparent layer may be present on the stack as a cover layer that protects the underlying layers from the environment. This layer may consist of one of the above mentioned substrate materials or of a transparent resin, for example, an UV light-cured poly(meth)acrylate with, for example, a thickness of 100 μm .

Such a relatively thin cover layer allows a high numerical aperture (NA) of the focused radiation beam, e.g. $NA=0.85$ and must be of relatively good optical quality and homogeneous. A thin 100 μm cover layer is e.g. used for the Blu Ray Disc (BD). If the radiation beam enters the stack via the entrance face of this transparent layer, the substrate
5 may be opaque.

The surface of the substrate of the optical data storage medium on the side of the recording layer is, preferably, provided with a servotrack that may be scanned optically with the focused radiation beam, e.g. a laser-light beam. This servotrack is often constituted by a spiral-shaped groove and is formed in the substrate by means of a mould during
10 injection molding or pressing. This groove may alternatively be formed in a replication process in a synthetic resin layer, for example, of an UV light-cured layer of acrylate, which is separately provided on the substrate. In high-density recording such a groove has a pitch e.g. of 0.5 - 0.8 μm and a width of about half the pitch.

High-density recording and erasing can be achieved by using a short-
15 wavelength laser, e.g. with a wavelength of 670 nm or shorter (red to blue).

The phase-change recording layer can be applied to the substrate by vapor depositing or sputtering of a suitable target. The layer thus deposited is amorphous. In order to constitute a suitable recording layer this layer must first be completely crystallized, which is commonly referred to as initialization. For this purpose, the recording layer can be heated
20 in a furnace to a temperature above the crystallization temperature of the phase change alloy, e.g. 180°C. A synthetic resin substrate, such as polycarbonate, can alternatively be heated by a laser-light beam of sufficient power. This can be realized, e.g. in a special recorder, in which case the laser-light beam scans the moving recording layer. Such a recorder is also called initializer. The amorphous layer is then locally heated to the temperature required for
25 crystallizing the layer; while preventing that the substrate is being subjected to a disadvantageous heat load.

The invention will be elucidated in greater detail by means of exemplary
30 embodiments and with reference to the accompanying drawings, in which

Fig. 1 shows a schematic cross-sectional view of an optical data storage medium in accordance with the invention,

Figs. 2A, 2B and 2C each show the maximum DC-erase velocity ($V_{e \max}$) as a function of the thickness of I2 (A), Ag-layer (B) and phase-change recording layer (C). The phase-change material was $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$,

5 Figs. 3A, 3B and 3C each show the time gap (as a fraction of the period T) at 90 % of the maximum modulation as a function of the maximum DC-erase velocity. For $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$ phase-change material the effect of variation in I2 thickness (Fig.3A), Ag (Fig.3B) and phase-change thickness (Fig.3C) is shown,

Figs. 4A, 4B and 4C each shows the maximum DC-erase velocity as a function of different dopants,

10 Figs. 5A and 5B respectively show the melt power P_{melt} (in mW) as a function of I2 thickness d_{I2} at 8x DVD+RW speed for a $P = 14$ nm $\text{Ge}_{12}\text{Sn}_{25}\text{Sb}_{63}$ phase-change layer (5A) and P_{melt} as a function of recording speed V_{rec} for $P = 14$ nm $\text{Ge}_{12}\text{Sn}_{20}\text{Sb}_{68}$ and I2 = 8 nm ZnS/SiO_2 (5B),

15 Fig. 6 shows the optical contrast C as a function of recording layer thickness d_P , for a GeSnSb phase-change material with I2 = 6 nm $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and 3 nm Si_3N_4 .

In Fig.1 the rewritable optical data storage medium 20, e.g. a DVD+RW disk, for high-speed recording by means of a focused radiation beam 10, has a substrate 7 and a stack 2 of layers provided thereon. The stack 2 has a first auxiliary layer 3, made of $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ having a thickness of 90 nm, a second auxiliary layer 5, made of $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ having a thickness of 6 nm, and a recording layer 4 made of a phase-change material of the alloy with a composition $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$. The heat conduction coefficient λ of $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ is 8.7 W/mK. The recording layer 4 has a thickness of 14 nm and is
 25 interposed between the first auxiliary layer 3 and the second auxiliary layer 5. A third auxiliary layer 6 made of Ag with a thickness $d_{I3} = 150$ nm acting as a heat sink is present at a side of I2 opposite to the side of the recording layer. A fourth auxiliary layer 8 is present sandwiched between the third auxiliary or reflective layer 6 and the second auxiliary layer 5 screening the third auxiliary layer 6 from a chemical influence of the second auxiliary layer 5.
 30 The fourth auxiliary layer comprises Ge_3N_4 and has a thickness of 3 nm. Si_3N_4 and Ge_3N_4 have a larger heat conduction coefficient λ than $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$. Si_3N_4 has a λ of 26 W/mK. The maximum DC-erase velocity $V_{e \max}$ was determined as the maximal linear disc velocity at which I14 carriers, i.e. nT marks with $n=14$, initially written with a typical carrier-to-noise ratio of 45 dB, could be reduced at 25 dB.

A second substrate 7, made of PC having a thickness of 0.6 mm is present adjacent the third auxiliary layer 6.

Sputtering provides the layers 3, 4, 5, 6 and 8. The initial crystalline state of the recording layer 4 is obtained by heating the as-deposited amorphous recording layer 4 in an initializer by means of a continuous laser-light beam to above its crystallization temperature.

In each of Figs. 2A, 2B and 2C the maximum DC-erase velocity (V_{\max}) as a function of the thickness of I2 (Fig. 2A), Ag I3-layer (Fig. 2B) and phase-change recording layer (Fig. 2C) is shown for a $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$ phase-change layer. The phase-change material was $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$. In the present invention, we state that the speed of a phase-change disc is also dependent on the layers and layer thickness of the optical stack.. It is observed that the speed increases for thick I2 and phase-change and decreases for thick I3.

In each of Figs. 3A, 3B and 3C the time gap (as a fraction of the period T) at 90 % of the maximum modulation as a function of the maximum DC-erase velocity is shown. This is the minimum gap allowed between write pulses to prevent backgrowth by the subsequent write pulse as a function of the recording speed of the disc. The gap was determined from so-called modulation-reduction experiments, in which I11 carriers are written with an increasing number of pulses and the modulation is measured. With increasing number of pulses to write the I11 (nT with $n=11$) carrier, the gap between pulses becomes shorter (22 ns-2 ns @ 4x DVD+RW) and backgrowth by subsequent write pulses may occur, which results in a reduction of the modulation. The curved line with solid squares is the 'composition line' where the disc speed is varied by adjusting the Ge-content in the phase-change layer. Solid squares represent GeSnSb compositions in a moderately cooled stack with I2 = 12 nm $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and 3 nm Ge_3N_4 , and 150 nm Ag. The dotted straight lines represent write strategies (WS); a disc with coordinates below such a line can be recorded with that WS. Two WS (1T or 2T) and the maximum laser pulse time are plotted. For $\text{Ge}_{13}\text{Sn}_{20}\text{Sb}_{67}$ phase-change material the effect of variation in I2 (Fig. 3A), Ag (Fig. 3B) and phase-change recording layer thickness (Fig. 3C) is shown. Decreasing the thickness of I2, the thickness of the phase-change recording layer P and increasing the thickness of I3 can shift the points downwards in Figs. 3A, 3B and 3C, so that recording with a simpler WS becomes possible. It should be noted that choosing for I2 a layer with a higher thermal conductivity, like Ge_3N_4 or Ta_2O_5 would give a results similar to lowering the thickness of I2. So a well-designed optical stack is important to diminish recrystallization within the write pulse. As said the amount of backgrowth recrystallization depends on the crystallization speed of the

phase-change material and the heat transport in the stack. It may be clear that especially for fast-crystallizing materials heat transport should be efficient to prevent recrystallization during writing. It is observed that at speeds over 35 m/s (10x DVD+RW) the moderately cooled discs of the composition line (solid squares) can only be recorded with complicated
 5 WS (3T or 4T), or with a 2T WS with extremely short pulses of 2 ns or shorter.

To summarize, it is stated that crystallization speed and backgrowth properties of the disc depend on, besides the phase-change composition, the thickness of I2, heat sink layer I3 and phase-change recording layer. Especially at linear velocities over 35 m/s (recording speeds over 10x DVD+RW), efficiently cooled stacks have to be designed that
 10 facilitate recording with relatively 'simple' WS. Effectively, this means I2- thickness below 9 nm if $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ is used as the dielectric layer, and/or phase-change layer thickness d_p below 15 nm, in combination with a fast crystallizing phase-change material.

In each of Figs. 4A, 4B and 4C the maximum DC-erase velocity as a function of dopants is plotted. The most important way to tune the crystallization speed of GeSnSb-
 15 based compositions is by varying the Ge-content. Fig. 4A shows the maximum DC-erase velocity as a function of the Ge-concentration. It is observed that between 10 and 15 % Ge, the crystallization speed increases dramatically. For this reason, it may be helpful to set the crystallization speed by variation of other elements. From Fig. 4A it can be observed that increasing the Sn concentration increases the crystallization speed. By addition of In, Ag or
 20 Cu, or other elements the crystallization speed can be lowered (Figs. 4B and 4C). The first solid square of Fig. 4B corresponds to the label (B) in Fig. 4A.

In Figure 5A and 5B respectively the melt power P_{melt} (in mW) as a function of $d_{I2} = (\text{ZnS})_{80}(\text{SiO}_2)_{20}$ at 8x DVD+RW speed for a $P = 14$ nm $\text{Ge}_{12}\text{Sn}_{25}\text{Sb}_{63}$ phase-change layer (5A) and P_{melt} as a function of recording speed V_{rec} for $P = 14$ nm $\text{Ge}_{12}\text{Sn}_{20}\text{Sb}_{68}$ and $I2 = 8$
 25 nm $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ (5B) are shown. The value of the parameter d_{I2} at the bottom side is in practice limited by the sensitivity of the medium. P_{melt} is the minimum (DC) power to melt the phase-change layer. It is observed that the sensitivity decreases with d_{I2} , i.e. larger powers have to be applied to write data marks. Fig. 5B shows furthermore that at high speeds larger powers are needed to melt the phase-change material, as a result of the shorter dwell time of
 30 the laser spot at a certain position at the disc. In practice, this sets limits to the minimum I2-thickness at high speeds, as no infinite laser powers can be applied. For current high power laser diodes, a maximum power on the disc of about 20 mW is reasonable.

In Figure 6 the optical contrast C as a function of phase-change layer thickness d_p for phase-change material GeSnSb with $I2=6$ nm $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and 3 nm Si_3N_4 is

shown. The lower limit of the phase-change layer thickness d_p is determined by the optical contrast C that can be achieved for a 'common' optical stack. Fig. 6 shows that the maximum optical contrast C for a stack with 12 of 6 nm $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ and 3 nm Si_3N_4 and a Ag heat sink decreases rapidly with the phase-change layer thickness d_p . Therefore, a minimum

5 phase-change thickness d_p of about 8 nm is proposed for single layer DVD+RW.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The

10 word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.